APPLICATION

FOR

UNITED STATES LETTERS PATENT

PATENT APPLICATION

SPECIFICATION

TO ALL WHOM IT MAY CONCERN:

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METHOD AND APPARATUS FOR MANAGING PROCESS TRANSITIONS

Reference To Pending Prior Patent Application

This patent application claims benefit of pending
prior U.S. Provisional Patent Application Serial No.
60/248,402, filed 11/14/2000 by Rajagopalan Srinivasan
et al. for METHODS AND APPARATUS FOR MANAGING PROCESS
TRANSITIONS (Attorney's Docket No. NUS-14 PROV), which
patent application is hereby incorporated herein by
reference.

Field Of The Invention

This invention is directed to a method and
apparatus for aiding operators and computer programs
in managing process transitions during the operation
of a complex process facility such as a chemical
process plant, nuclear power plant, and semiconductor
manufacturing facility. Examples of transitions that
commonly occur in plants include, but are not
restricted to, startup or shutdown of the plant,
startup or shutdown of a unit in the plant, switching

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of a unit from a normal operation state to a different

state for the purpose of maintenance or regeneration,

variations made in the operating conditions to

accommodate feed grade changes in a plant, variations

5   made in the operating conditions to accommodate

product slate changes in a plant, etc. Examples of

computer programs that would be aided by the apparatus

in this invention include, but are not restricted to,

regulatory and supervisory controllers, alarm

10   generation and management systems, advanced control

systems, fault diagnosis systems, etc. Also this

invention describes a method and system for monitoring

processes during transitions, which identifies

abnormalities and informs the plant operator regarding

15   the same. Since none of the existing monitoring

techniques can be used for monitoring transitions and

since the probability of fault is higher during

transitions than at steady state, such a system would

be of immense help to operators.

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Background Of The Invention

The operation of a complex process facility requires the assimilation of a large amount of data generated frequently from sensors, inferring the state of the process from these data and executing regulatory and supervisory actions to ensure safety and efficiency. While much of the operation of the modern complex process facility is automatically controlled, the execution of the process during transitions requires extensive human intervention and supervision. These operator interventions during transitions include starting or stopping process units such as pumps and compressors, disabling or enabling controllers, and reconfiguring units and controllers with different parameter settings. Transitions result in substantial changes in the values of one or more process variables. During transitions, some of these plant variables may therefore take values substantially different and outside their normal, steady state range. Because of the large changes and the unusual values of the process variables, plant

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computer programs that are configured for only one

operating condition generate incorrect results. One

example of this is the alarm system that would

generate spurious alarms if it were not specifically

5   configured for the transition. Other such computer

programs include those for advanced control, unit

optimization, etc. Operators therefore disable and/or

ignore the results of such plant computer programs

during transitions. The operator actions, mentioned

10   above, that bring about a transition have to be

performed at a specified time dependent on the status

and conditions of the plant. Failure in this can lead

to abnormal situations.

D. H. Hwang and C. Han, "Real-time Monitoring For

15   A Process With Multiple Operating Modes", Control

Engineering Practice, 7, 891-901, 1999, proposed a

statistical method for monitoring processes with

multiple operating modes. Their technique is

applicable only for operation modes a that share

20   common characteristics and do not introduce a

significant amount of nonlinearities in the process

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behavior.   Many common transitions such as a cold

startup of a reactor or distillation column, decoking

of a furnace, swinging of units for product or feed

grade changes, and others result in significant

5   nonlinear changes and cannot be monitored by their

approach.

Process transitions are typically carried out by

operators by following a standard operating procedure.

A few techniques exist for monitoring the execution of

10   the operating procedures in a process plant.

A method suggested in U.S. Patent No. 5,511,004,

issued April, 1996 to Dubost et al., establishes a

reference state and a current state for an industrial

evolutionary process from physical parameters measured

15   on all the equipment items employing the evaluating

process.   These two states are compared, parameter by

parameter, by resorting to fuzzy logic for classifying

the quantities, and a diagnosis is established using

expert rules.

20   U.S. Patent No. 5,070,468, issued December, 1991

to Niinomi et al., presents a fault diagnosis system.

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The normal range of process data is stored in the system and is employed for online comparison to determine if the process is normal or not. Patterns exhibited by the process variables for different fault

5   patterns are detected and recorded in the system. When a fault is identified, the pattern is compared with this stored database and the fault is diagnosed.

U.S. Patent No. 5,392,320, issued February, 1995 to Chao et al., provides a monitoring system for a

10   core of the nuclear reactor. Some process variables that need to be continuously monitored are identified. A database is maintained for normal and abnormal operation. Comparison of online data is done with this database to identify the plant situation.

15   An approach to monitoring a transient is described in U.S. Patent No. 4,678,622, issued July, 1987 to Rowe et al. This makes use of the known phenomenon that during the startup in a nuclear reactor, the neutron density increases. However,

20   there could also be an increase in the neutron density due to some abnormality. A system is built to detect

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the abnormality. If the startup is done normally, the neutron density increases slowly, whereas if there is a fault, there is an exponential increase. This difference is used for identifying the fault during

5   startup.

A method and apparatus for fault diagnosis is described in U.S. Patent No. 5,099,436, issued March, 1992 to McCown et al. In this system, the online values of variables are continuously monitored. If

10 there is any deviation from normal, it is mapped to any pre-trained event (fault). It also consists of a symptom-fault model that can determine the cause of the failure.

U.S. Patent No. 5,023,045, issued June, 1991 to

15 Watanabe et al., describes a neural network based technique for detecting malfunctions in plants. The neural network is trained with normal and different runs of data with malfunctions. So this system, when used with online run, can identify trained

20 malfunctions. An application on a nuclear power station has been discussed. Since this application

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requires training, it can function only for known faults for which the network has been trained.

A few other techniques also exist for monitoring the operating procedures for nuclear and thermal power plants. However, all of these techniques employ raw sensor values in their analysis.

There exist some techniques in published literature which use signed directed graphs (see Iri, M., Aoki, K., O'Shima, E. and Matsuyama, H., "An Algorithm For Diagnosis Of System Failures In Chemical Processes", Computers and Chemical Engineering, 3, 489-493, 1979) and trends (see Rengaswamy, R. and Venkatasubramanian, V., "A Syntactic Pattern Recognition Approach For Process Monitoring And Fault Diagnosis", Engineering Applications Of Artificial Intelligence, 8(1), 35-51, 1995; Vedam, H. and Venkatasubramanian, V., "A Wavelet Theory Based Adaptive Trend Analysis System For Process Fault Diagnosis", Proceedings Of The American Control Conference, 309-313, 1997) for monitoring steady state processes. During process transitions, the process is

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in a dynamic state and variable profiles change significantly. For monitoring such process behavior, none of the existing techniques (such as neural networks, signed directed graph or trend-based methods) could be used.

First, consider a signed digraph based technique. During process transitions, since interactions between the different variables vary with process operating conditions and time, a general cause-effect relation between process variables could not be obtained. So signed digraph based techniques cannot be used for monitoring process transitions.

In the trend-based approaches, the evolution of a process variable is classified based on its shape into slowly increasing, drastically increasing, constant, etc., by calculating the second order derivatives of the process variables. These are termed as *second-order trends*. First order derivatives of process variables result in trends which are classified into increasing, decreasing and constant. These are termed as *first-order trends*. Neither the second-order nor

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the first-order trend-based approaches can be applied

to monitor process transitions as described below. As

an example, consider the transition "startup of a

reactor" that is performed in three main phases: (1)

5   charging of reactants at room temperature (30° C) into

the reactor, (2) ramping up the temperature from 30° C

to 75° C over 1.5 hours, and (3) maintaining the

temperature at 75° C. Each process variable could

display different trends during different phases. The

10   temperature sensor in the above example would display

a constant trend in phase 1, an increasing trend in

phase 2, and a constant trend again in phase 3.

Existing trend-based approaches are designed for fault

detection in steady state operation and map a fixed

15   trend (such as increasing temperature) occurring at

any time with a fixed process state (such as a runaway

reaction). This can lead to wrong results when used

to monitor process transitions. In the above example,

while the increasing trend in temperature would be

20   diagnosed correctly as due to a runaway reaction if

the process is in phase 3, an increasing trend in the

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same temperature variable during phase 2 would be

misdiagnosed as due to a runaway reaction. Due to

this and other limitations discussed later, existing

trend based techniques can not be applied for

5   monitoring transitions.

Summary Of The Invention

It is an overall object of this invention to

provide a method and apparatus for aiding operators

and plant computer programs in managing a process when

10   it undergoes transitions.

It is a more specific object of the invention to

aid the operator of a complex process facility by

providing a computer-based system and a method of

15   operation which incorporate prior generated knowledge

of the process operation along with on-line plant

data, whereby to identify the current state of the

plant and monitor the plant during transitions.

It is a further object of the invention to

20   provide such a system and method of operation which

simultaneously provide the operator and other plant

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computer programs with information concerning the
current state of a process, section or subsection and
other useful, context-sensitive facts such as bounds
on the process variables and expected and observed
trends of these variables, steps in the transition
which have been completed earlier, and steps in the
transition which should be executed next.

This apparatus enables some plant computer
programs to be robust to operating mode changes and
reconfigure themselves to operate effectively during
different process transitions and across multiple
plant operating modes.

It is an additional object of the invention to
provide a system and method of operation, which
generates a permanent record of appropriate system and
process conditions at important moments of each
transition including its start, its completion, when
something is abnormal, the operator actions, their
magnitude, timing and sequence, etc. This record can
be queried to provide decision support for plant
operations and other activities that would gain by the

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knowledge of the transitions. An example of decision

support includes a list of transitions in the record

similar to a fully or partially specified one, the

process conditions during those, operator actions,

5   etc.

It is an additional object of this invention to

provide a system and method for tracking and

monitoring processes during transitions. Transitions

are typically carried out by operators by following a

10   set of standard operating procedures. The main

challenge in monitoring transitions is run-to-run

deviations. A technique is presented here which can

identify the current state of the operating plant

during a transition and perform context sensitive

15   monitoring. If any deviation from normal operation is

observed, the system flags the abnormality to the

operator for necessary recovery of the process.

Briefly, the present invention includes a new

method and apparatus for developing a generic facility

20   for the management of process transitions. The

apparatus employs a method for offline

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characterization of process plant and generation of a comprehensive knowledge base, which is deployed for real time mode-transition identification. Once the current plant state is identified, other subscribing applications are notified regarding the same.

The apparatus also includes a method for monitoring transitions (startup, shutdown, grade changes, etc.) in complex processes. Since trends alone are not sufficient for monitoring transitions, we have developed a technique called enhanced trends that include the process variable magnitude and the trend duration along with trend. The algorithm described employs a preprocessing technique to obtain process trends in addition to the quantitative information from the plant. The dictionary of possible transitions for each plant section is generated offline from the plant history data and stored corresponding to each sensor. The algorithm cannot only point out the region in the plant where an abnormality has occurred, but can also further resolve it to the level of a sensor.

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The apparatus also includes a method that allows
for run-to-run variations during process transitions.

A dynamic feature synchronization algorithm is
employed to synchronize profiles from different runs.

5   After synchronization, comparison of the expected
trend and observed trend is done by using a comparison
algorithm. Since transitions are usually performed by
following a set of operating procedures, this
knowledge is also made available to the system using a

10   Grafcet representation. If any fault is identified by
the system, the details of the fault, as well as the
current task in the operating procedure during which
the fault is identified, is informed to the operator.

15   Brief Description Of The Drawings

Fig 1. is a schematic diagram of the overview of
the invention;

Fig. 2 is a schematic diagram of the method for
hierarchically dividing the plant into sections and

20   subsections;

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Fig. 3 shows how a process variable can be

divided into periods of modes and transitions based on

the changes in the variable value;

Fig. 4 shows the decision-making sequence

5 followed by methods for identifying if a subsection is

in a mode or transition;

Fig. 5 shows the process knowledge base

generation technique;

Fig. 6 shows a schematic of the method for

10 transition identification;

Fig. 7 shows the Grafcet representation for a

startup procedure for a distillation column;

Fig. 8 shows the technique for comparing the

different elements of an enhanced trend; and

15 Fig. 9 shows a typical trend during different

runs of a process transition.

Detailed Description Of The Preferred Embodiments

The invention will now be described in the

20 context of a chemical process plant, but it should be

realized that it has application to a wide variety of

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complex process facilities such as, for example,

pharmaceutical operations, semiconductor and

microelectronics manufacturing, specialty chemicals,

paper and pulp mills, power plants, etc.

5   Any chemical plant is instrumented with numerous

sensors that monitor various plant variables such as

temperatures, flow rates, pressures, etc. The signals

generated by the sensors are fed to the plant

distributed control system (DCS) that performs and

10   coordinates regulatory control of some of the

variables. These variable values are also displayed

to operators through monitors in the control room.

Some of these values are also used by other plant

computer programs such as an alarm system, a unit

15   optimization system, etc., which help the operator to

run the process safely and efficiently. During large

periods of time, the plant is typically operated near

one or more steady state conditions. During such a

steady state condition, most process variables will

20   vary slightly due to noise and disturbances. These

variations would be within a narrow range around the

fixed steady state value. However, not infrequently,

the plant (or one of its constituent sections or

subsections) will undergo a transition aimed at moving

it from one steady state to another. Transitions are

5   normally executed by plant operators who follow

previously defined procedures to start or stop process

units, controllers and instrumentation, or to

reconfigure them with different settings so that the

plant settles down to a different steady state. Many

10   plant computer programs are configured solely for

steady state operations and do not function

satisfactorily during such transitions. Operators

therefore disable them, or ignore or override their

results, during the transitions.

15   All of what has been described so far is

currently found in a typical chemical plant. The

present invention provides a system that provides

context-sensitive information and guidance to the

operator during the transitions and automatically

20   reconfigures other plant computer programs. Examples

of automatic reconfiguration include the turning

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on/off of various computer programs, changing

parameter settings, etc.   An overview of this scheme

is presented in Fig. 1.   As shown in Fig. 1, the

supervisory method identifies the current operating

5   state of the plant.   This information is provided to

other clients such as alarm management systems, fault

detection and diagnosis systems, etc., which configure

themselves according the current plant state.

The purpose of the apparatus is fourfold:

1.   to assess the current state of the process,

including the current mode of the process, or the

transition being executed;

2.   to provide the process state and any

necessary information to the plant operator and/or

15   plant computer programs;

3.   to monitor the process for the normal

execution of a transition; and

4.   to continuously track the execution of

operating procedure during transition and inform the

20   plant operator of the successful completion of the

same.

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First, there is a way for hierarchically decomposing the process and variables into a number of sections and subsections. When doing this, it is recommended that one use the process flow diagram (or at least a sketch of its physical arrangement) as well as the placement of the sensors. Each section can further be subdivided into one or more sections and/or subsections, and so on. Each subsection comprises of a set of one or more process variables whose values are measured periodically. A change in the value of any of these variables would indicate that the corresponding subsection is undergoing some change.

A plant can be decomposed into one or more sections. For example, a refinery could be divided into a crude distillation unit, a vacuum distillation unit, a catalytic cracking unit, etc., that are called sections. This division is based on a number of factors including the functions and purpose of the major units, their interactions and interconnections, the extent of mutual dependence during their operations, their physical location, etc. Each

section can be further divided such that it contains

at least one sections or subsection. A subsection

comprises of one or more sensors (also called variable

tags) and performs a supporting function to its parent

5   section. In the above example, the catalytic cracking

unit section can be subdivided into a reactor-

regenerator subsection, a feed preheater subsection, a

main fractionator section, etc. The main fractionator

section in turn is decomposed into an overhead

10   subsection, a bottoms subsection and the column

subsection. This hierarchical decomposition scheme is

depicted in Fig. 2.

Next, there is a way of classifying the state of

a subsection or section into modes and transitions as

15   shown in Fig. 3. A subsection is said to be in a mode

if, and only if, the values of all the variables with

the subsection lie within a narrow range. The modes

of subsections can be classified based on the nature

of the changes in the process variables into a steady

20   mode, oscillatory mode. A subsection is defined to be

undergoing a transition if any of the variables with

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the subsection varies significantly. Transitions of
subsections can be classified as sharp transitions,
upset transitions, slow drift transitions, desired
transitions, etc. A section is said to be in a mode

5   if, and only if, all its subsections are all in modes.
A section is said to be undergoing a transition if any
of its immediate subsections are in a transition.
Each subsection or section will, at any time, be in
exactly one of several possible modes or transitions.

Next, a mode of a subsection can be characterized
by specifying key descriptors such as an upper and
lower bound for each process variable in the subgroup
within which that variable would vary if the subgroup
is in that mode. A non-empty subset (i.e., at least

15 one) of process variables in a subsection would
undergo significant changes when the subsection
undergoes a transition. This subset of variables is
called the set of key variables for that particular
transition. A transition in a subsection is

20 characterized by descriptors such as the subset of key
variables along with distinct features in their

variation as the transition is executed, the mode of the subsection immediately prior to the beginning of the transition, the mode of the subsection immediately after the completion of the transition, the start time of the transition and the end time of the transition, etc. The distinct features of the key variables include the sequence of trends, the duration for which each trend persists, variable values at the beginning and termination of each trend, the maximum and minimum values of the variables within the transition, etc.

As mentioned earlier, a section is said to be in a mode if each of its constituent subsections are themselves in a mode. The mode of a section is characterized by the values of the mode of its constituent sections and subsections. A section is said to be in a transition if even one of its constituent sections and subsections undergoes a transition. The transition of a section is characterized by the state (mode or transition) of each of its constituent sections and subsections, and this information may be recorded in a look up table.

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The section's characterization therefore includes this lookup table.

A self-contained knowledge base that contains all the information required for managing process transitions can be developed. The knowledge base of the apparatus comprises of the following constituents:

1.   an hierarchical description of the process into sections and subsections as described above;

2.   a list of modes and transitions for each of the process sections and subsections as described above;

3.   the classification and characterization of each mode as described above; and

4.   the classification and characterization of each transition as described above.

The above-described knowledge base can be completely developed using the aforementioned method for the plant's hierarchical decomposition, followed by including the list of modes and transitions, followed by characterizing each mode and transition. This knowledge base can be developed in one step or

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developed incrementally by following the same methods

and appending new sections, subsections, modes and

their characterization, transitions and their

characterizations, etc.

The list of modes and transitions and their

characterizations can be developed using the knowledge

about the plant and its operation.

Alternatively, if historical data from the plant

operation is available, the list of modes and

transitions and their characterizations can be

developed using the following method.

There is a method for generating the list of

modes and transitions for every subsection, section

and plant if process historical data is available for

every tag. This method is as shown in Fig. 4 and is

based on dividing the plant historical data into

regions of modes and transitions, using the prior

developed description of the process hierarchical

decomposition. This method also requires other

selected process information including limits for each

tag andpre-specified values for tuning parameters.

The limits required include the maximum and the

minimum value that can be reported by the transmitter

for each tag, the transmitter range for each tag, etc.

The pre-specified tuning parameters include a

5   threshold for each tag. This threshold is defined to

be the maximum allowable variation within a window for

constancy and is typically selected to be a small

percentage (~5%) of the transmitter range.

Once plant tags have been hierarchically grouped

10   into sections as described above, they can be used for

identifying subsection modes and transitions. Plant

historical data corresponding to the tags is used in

the analysis. Trends can be generated for each tag

using any method including, but not restricted to, the

15   wavelet-based trend generation algorithm reported by

Vedam, H. and Venkatasubramanian, V., "A Wavelet

Theory Based Adaptive Trend Analysis System For

Process Fault Diagnosis", Proceedings Of The American

Control Conference, 309-313, 1997. Wavelet

20   approximation coefficients at multiple levels are also

generated for each tag. A multitude of other wavelets

including the Haar wavelet can be employed for this

purpose. Portions of the historical data for which

the variable shows a constant trend are identified

using the trend information generated earlier. These

5   portions are marked as modes for that tag. The mode

information generated for all the tags in the

subsection is matched to obtain the portions where all

of the variables in the subsection remain nearly

constant. These portions are identified as the modes

10   for that subsection. Modes are characterized by the

maximum and minimum values of each tag within the

portion. The mode information for the subsection

generated above is then analyzed for duplicate modes.

Two modes of a section, M_1 and M_2, are considered to be

15   the same if their characterizations are essentially

similar. A multitude of similarity metrics can be

used to compare the characterization of two modes. In

one such metric, two modes of a subsection, M_1 and M_2,

are said to be the same if the shortest distance

20   between the maximum (or minimum) value of a tag during

M_1 is no further from the minimum (or maximum) value of

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the tag during M_2 than a small pre-specified threshold. A typical value for this threshold is 5% of the tag's transmitter range. The similarity measure described above can be replaced with other similarity metrics.

5 If consecutive duplicate modes are encountered, they are merged together to produce a single mode. The modes are also checked for their duration, and modes shorter than a pre-specified duration are eliminated by merging these portions along with the transition.

10 After the modes have been identified as described above, the remaining portions of the historical data that have not been marked as modes are now marked as transitions. Key variables are then identified for each transition as described above. Transitions are

15 then characterized using the distinct features in the key variables including the sequence of trends, the duration for which each trend persists, variable values at the beginning and termination of each trend, maximum and minimum values of the variable within the

20 transition, etc., as described earlier.

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The modes and transition characterizations generated above are used to create an event list consisting of all the events - mode or transition - for a subsection. The events for sections and plants are inferred from the events of the subsections of which it is comprised. An event look-up table is generated for each section and comprises each of the different combinations of events of subsections and the corresponding event for the section. The entire event look-up table, or any selected consistent subset such as those combinations of subsection events that were observed in historical data, can be used. Using the above described method, the list of modes and transitions and the characterizations for each mode and transition can be generated from process history data.

Next, there is a method for identifying the current process state. The apparatus implements a method for identifying the current state of the process and each section and subsection and it uses the knowledge base generated from the historical data.

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The steps in on-line identification of the state

of the process are shown in Fig. 5. The method takes

as input:

1.   the knowledge base previously generated for

5   the process;

2.   the current values of process variables; and

3.   values for tuning parameters selected by

user.

The knowledge base generated offline is imported

for use by the method to identify the current process

10   state. Initialization calculations are performed and

user-supplied tuning constants are assigned. The

sensor data for all the plant tags sent from the DCS

is separated based on the basis of plant groupings.

15   For each subsection, the current sensor data is

compared with the knowledge base of the modes possible

for that group. If the value of each variable

belonging to the subsection falls within the upper and

lower limits for a given mode, the subsection is

20   identified to be in that mode. To avoid false signals

of a mode, the method waits for a certain minimum

duration for which the subsection remains in the given

mode before the current mode information is signaled.

A user-defined parameter is employed to determine this

minimum duration and could take any positive integer

5   value. This procedure is repeated for all the

subsections. If the subsection is not identified to

be in any of the modes from the knowledge base, but

all variables in that subsection are varying within

user defined narrow bounds, then the subsection is

10 said to be in an unknown mode. If even one of the

variables in the subsection is varying beyond its

bounds, the subsection is said to be in a transition.

The current transition is identified using the

procedure described in Fig. 6. This procedure

15 compares the currently evolving transition with the

transitions existing in the imported knowledge base.

The current transition can be identified using a

similarity metric to compare its characterization with

the characterizations of the transitions in the

20 knowledge base. A multitude of similarity metrics can

be used to compare the characterization of the current

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transition with that of a transition in the knowledge

base. In one such metric, wavelet decomposition of

the plant sensor is carried out for each variable in a

subsection undergoing the transition to obtain   .

5   approximation coefficients for as many levels as is

necessary. The number of levels of decomposition is a

user-defined parameter and typically takes a value of

between 1 and 5. These wavelet coefficients are then

compared with the wavelet coefficients for transitions

10   available in the knowledge base. Since the previous

mode is known, the comparison can be restricted to

only those transitions that are known to occur from

this mode. A norm of the difference between the

wavelet coefficients is obtained at each level, and a

15   sum of all these norms is computed. The transition

that provides the least norm is flagged as the current

transition if the value of the norm is smaller than a

user defined parameter. If the value of the smallest

norm is larger than this user defined parameter, than

20   the transition is flagged as an unknown transition.

This procedure is repeated for each subsection that is

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currently undergoing a transition. The similarity

measure described above can be replaced with other

similarity measures.

Based on the events identified for the

5   subsections, the event for the sections is inferred by

looking-up the event lookup table available in the

knowledge base for each section. This procedure is

carried out for all the sections by moving up the

plant hierarchy.

Thus, the above-mentioned method identifies and

10   tracks the process by identifying the current state -

mode or transition.

The transition in a process consists of several

phases as mentioned earlier. In addition to tracking

15   the current state of the process, an additional

method exists to track the process within the

transition. This method takes as its inputs:

1.   a knowledge of the common operating policies

for the plant, commonly available in the form of

20   standard operating procedure of the transition; and

2.   the distinct features of the process

variables during the transition.

The phases in the operation or the standard

operating procedure is represented schematically using

a Grafcet representation as shown by Viswanathan, S.,

Johnsson, S. C., Srinivasan, R., Venkatasubramanian,

V. and Arzen, K. F., "Automating Operating Procedure

Synthesis For Batch Processes: Part I.", Knowledge

Representation And Planning Framework, Computers And

Chemical Engineering, 22 (11), 1673-1685, 1998. The

actions to be performed are represented by Grafcet

steps, and the condition for the end of each task is

represented using a Grafcet transition. For example,

consider the startup of a distillation column, which

consists of the following steps:

1.   initially put all the controllers in manual;

2.   open the cooling water to the condenser;

3.   fill liquid of higher bottom product

composition in the reboiler and start the reboiler

heating, and operate the column in full reflux;

4.   when the product starts collecting in the top and when the tray temperatures remain constant, start the feed pump and operate the column under constant reflux; and

5.   when the column temperatures remain constant, then the column has reached steady state.

The Grafcet representation for this particular example is given in Figure 7.

For the purpose of tracking and subsequent monitoring of transition, a subset of the distinct features of a process variable (including variable trend, duration of trend and variable value at the beginning and end of the trend) is termed an atom. The series of this atom for a process variable is termed the enhanced trend of that process variable. This information for every process variable during the current transition is obtained from the previously generated knowledge base and is termed as the dictionary of that variable. Portions of the enhanced trend corresponding to each phase in the operating procedure (represented by a Grafcet step) are stored

corresponding to its Grafcet step. Thus, every atom

in the dictionary has a corresponding Grafcet step to

which it belongs.

The method for tracking the process within a

5 transition continuously looks at the trend of the

evolving process variable. The combination of

variable trend, duration of trend, and variable value

at the beginning and end of the trend for a real-time

process variable is termed a real-time atom. The

10 logic behind the tracking method is that, there could

be minor deviations in the magnitude of the process

variable and the start and end time of different

phases, but the trend of the process variable should

essentially follow the trend as given in the

15 dictionary.

A dynamic feature synchronization algorithm for

this tracking is shown in Fig. 8. As shown in Fig. 8,

the algorithm starts with the first real-time atom. A

comparison of trend is done with the first dictionary

20 atom. Then for subsequent real-time atoms, the trend

is compared with the current dictionary atom and the

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next one. If the trend of a real-time atom is equal

to the next dictionary atom, then the comparison of

the subsequent real-time atoms is done from there;

otherwise, for the subsequent real-time atoms, trend

5   is compared with the current dictionary atom. Thus,

using this dynamic feature synchronization method, the

dictionary atom to which the real-time atom

corresponds is identified. Once the dictionary atom

is identified, the corresponding phase in the

10   operating procedure, currently being carried out in

the plant, can be identified.

This information regarding the current phase of

transition may be broadcast to different sections of

the plant. This kind of tracking helps in context

15   sensitive process operation and recovery in the case

of any abnormality.

The dynamic feature synchronization algorithm

described above can be replaced with other equivalent

ones such as dynamic time warping. This tracking

20   method is an optional method, which can be used if the

process current operating phase needs to be identified

for a process.

Finally, there exists a method for monitoring

processes during a transition. This method takes as

5   input the enhanced trend of the process variables.

This method is independent of the Grafcet

representation for operating procedures. If the

operating procedure information is made available, it

may be used. This method essentially consists of a

comparison of the different elements of the real-time

enhanced trend with that of the dictionary as shown in

Fig. 9. For this, the first step is the

identification of the dictionary atom to be compared

with. The dynamic feature synchronization algorithm

15   discussed above provides this information of the

dictionary atom. This tracking method identifies the

corresponding dictionary atom for a real-time atom.

If the Grafcet information is made available to the

system, it additionally provides the phase being

20   performed. As per the flow diagram shown in Fig. 9,

first the trend between the real-time and the

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dictionary atom are compared. If there is a mismatch in trend, it is concluded that there is an abnormality in the process variable, otherwise the comparison proceeds. Then comparison is performed between the

5 process variable magnitude and the trend duration between the real-time and dictionary atom. From this, the matching degree for each process variable is calculated. The degree of fault of the whole process is calculated as a function of degree of fault of

10 individual sensors.

The monitoring method identifies any abnormality during the process transition and informs the operator regarding the same. The details of the sensor (the sensor type, tag name), kind of abnormality (deviation

15 in shape or magnitude or time) and the extent of deviation from normalcy are reported to the operator. This will help the operator rectify and bring the process operation back to normal.

Identification of trend of the process variable

20 is an important step since trend is considered as the main criterion for synchronizing the real-time process

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with the dictionary. Both the second-order and the

first order trends discussed above can be used for

this purpose. Using second-order trends allows for a

fine comparison between real time trends and those in

the knowledge base where even minor deviations can be

detected quickly. On the other hand, the use of

first-order trends provides a coarse comparison that

is more robust to run-to-run deviations. The method

allows for the user to select either the second order

or the first order trend based on the how closely the

real-time process is required to follow the

dictionary.

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